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PREDICTING INDIVIDUAL LISTENER CONFUSIONS IN THE CLASSIFICATION OF COMPLEX, STEADY-STATE SOUNDS

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Human Performance Laboratory
Department of Psychology
The Catholic University of America

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The classification model proposed by Howard, Ballas and Burgy (1978) estimates attentional capacity and how it is allocated to the relevant dimensions. It was hypothesized that capacity will vary as a function of individuals but that the allocation of capacity is a function of dimensional relevance. A classification experiment was conducted using amplitude-modulated noise with modulation frequency (Tempo) and waveform attack (Quality) as relevant dimensions. Subjects were required to classify sixteen sounds into eight categories emphasizing one of the dimen-

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sions for eight blocks (1536 trials) and then the other dimension for eight blocks. Capacity was estimated by the model and was equivalent for both classification tasks for individual subjects. Allocation of capacity reflected dimensional relevance.

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The aural classification model developed by Howard, Ballas, and Burgy (1978) states that classification is a process of estimating the probability of membership in each category and chosing the category which maximizes the probability of being correct. Estimates of the probability of category membership are based on the distance from the stimulus to the category prototype in a psychological space. Each category is represented by a region in the psychological space that surrounds the prototype for that category. The likelihood of category membership is determined by a set of Gaussian probability density functions centered at the category prototypes.

In the original research (Howard et al, 1978), the stimuli varied in two dimensions, and the probability distribution of a category was defined in a two dimensional space by the coordinates of the prototype and a variance for each dimension. The most important parameters estimated by the model are these variances. They are partly reflective of sensory noise and sensitivity, but Howard et al found that the variance on each dimension was greater than what would be expected if only sensory factors were involved. Other contributing factors may include an inaccurate memory for the category (Durlach & Braida, 1969) and uncertainty about the location of category boundaries (Gravetter & Lockhead, 1973).

Howard et al have described the overall variance in capacity terms and argue that it represents an upper limit on the amount of effort available for the task. As such, it might have both

sensory and memory components. However, the limited-capacity approach (Kahneman, 1973) implies that the demands of the different aspects of the task are being traded-off. Because of this, the limited capacity approach is particularly suited to multidimensional stimuli where the listener must attend to more than one stimulus attribute to determine a classification. The Howard et al (1978) classification model was developed specifically to be used with multidimensional stimuli. Models developed by others have not yet been applied to more than one dimension although this extension has been considered (Macmillan, Kaplan & Creelman, 1977).

In the two dimensional case, the available effort will be allocated to one or both dimensions depending on the salience of the dimension. Factors which affect salience include discriminability, relevance of the dimension to classification, individual differences and prior learning (Kahneman, 1973). These factors should be associated with changes in the variance parameters estimated by the model. Howard et al found that the relevance of an aural dimension affected the allocation strategy as reflected in the estimated variances. In this experiment we examine individual differences in aural classification. The purpose of the study is to determine whether listener differences persist with changes in dimensional relevance. In particular, we are interested in whether the overall variance parameter remains stable for a particular individual with changes in dimensional relevance. To accomplish this, four listeners were tested on the same set of sounds in each of two conditions, one which

emphasized one dimension and one which emphasized the other dimension. The model will be used to estimate the overall attentional effort parameter as well as individual variance parameters for each dimension in each condition.

Method

Participants. Four undergraduate students were paid to participate. In order to obtain differences in performance, both naive and experienced listeners were used. The two experienced listeners were highly skilled in aural classification from prior experiments. Two naive listeners were solicited by advertisement. Initial monitoring of their performance indicated that they were not as skilled as the two experienced listeners. The four listeners included three males and one female, and all reported no hearing deficiencies.

Apparatus. All experimental events were controlled by a laboratory digital computer. Modulation waveforms were synthesized by the computer and output on a 12-bit digital-to-analog converter at a 5 kHz sampling rate. This signal was applied to the input of a laboratory-constructed transconductance operational amplifier circuit (RCA CA3084). The output gain of the operational amplifier was directly proportional to the amplitude of the modulation signal. These amplitude-modulated signals were delivered to listeners over matched Telephonics TDH-49 headphones with MX-41/AR cushions.

Stimuli. A set of 16 amplitude modulated noise signals was generated by combining four levels of modulation frequency (4, 4.8, 5.6, 6.4 Hz) and four levels of attack (43%, 57%, 71%, 86% of period). Following Howard et al (1978), the perceptual attribute corresponding to modulation frequency will be referred to as Tempo, and the attribute corresponding to attack will be referred to as Quality. These sounds differed from those used by Howard et al both in modulation frequency and attack. The modulation frequency steps were made closer in order to avoid possible ceiling effects. The levels of attack were chosen so that rise times of 20-40 msec would not be used. According to Cutting and Rosner (1974), perception of rise times in this interval is different than perception of rise times outside this interval.

The noise carrier was 20Hz-20kHz white noise (B & K Model 1402 random noise generator). The modulated signals had sawtooth waveforms with the percentage of attacks above. All signals were presented at about 65 dB SPL.

The 16 stimuli were partitioned into 8 categories in two ways. The Tempo partition included categories that differed on four levels in Tempo and only two levels in Quality. The Quality partition was formed in the reverse manner--two levels in Tempo and four levels in Quality. Thus each of the dimensions was more relevant in one partition and less relevant in the other. However, the stimuli were the same in both partitions.

Procedure. The listeners were tested individually in a sound-attenuated booth. They were told that their task was to learn to classify sixteen sounds into eight categories, two sounds per category. No specific instructions were given about how Tempo and Quality were to be used. Each trial began with a visual warning followed by a 2.5 or 3 sec presentation of one of the sounds. The two durations occurred equally often and were included to discourage a simple "peak counting" strategy. After the signal ended, the listener pressed one of eight keys (labled with CVC nonsense syllables of equal association value) to indicate the category for the sound. Feedback was provided after each trial.

All listeners received 192 trials in each of 8 blocks for a total of 1536 trials in each partition. After completing one partition, the listener was started on the other partition. Listeners LK and RO received the Tempo partition first and listeners JP and JG received the Quality partition first. Listeners RO and JG were the two experienced participants. Trials were randomized in each block. Listeners normally completed two consecutive blocks a day.

Results and Discussion

Performance of all listeners peaked within the eight blocks for both partitions. One listener, LK, did not peak until the eighth block and was tested for two additional blocks to determine whether her performance would continue to improve. Her performance on these two additional blocks was equivalent to that

on block eight. The overall performance for all four listeners on the Tempo and Quality partitions are presented in Figures 1 and 2, respectively.

Insert Figures 1 and 2 here

The performance under the Tempo partition was significantly better overall, but primarily for two of the four listeners. The overall percentage correct was 62% and 55% for Tempo and Quality respectively, averaged across the eight blocks and the four listeners. This difference was statistically significant ($\underline{z}$ = 7.87, $\underline{n}$ = 6144), but was due primarily to the performance of listeners JG and JP. These two did significantly better with the Tempo partition, which was the second partition for them ($\underline{z}$ = 4.42 and 10.53 for JG and JP, n = 1536). This indicates that there was some effect due to the order of the partitions. Since Tempo was generally the more effective cue, the added practice on it during the Quality partition, the first partition for JG and JP, may have raised their performance on the Tempo partition. The difference in performance under each partition was not significant for LK and RO who received the Tempo partition first.

The Gaussian classification model was used to estimate theoretical confusion matrices for each listener on each block. The theoretical matrices were determined by selecting standard deviation parameters for each feature that minimized the discrepancy between the theoretical and observed matrices in a

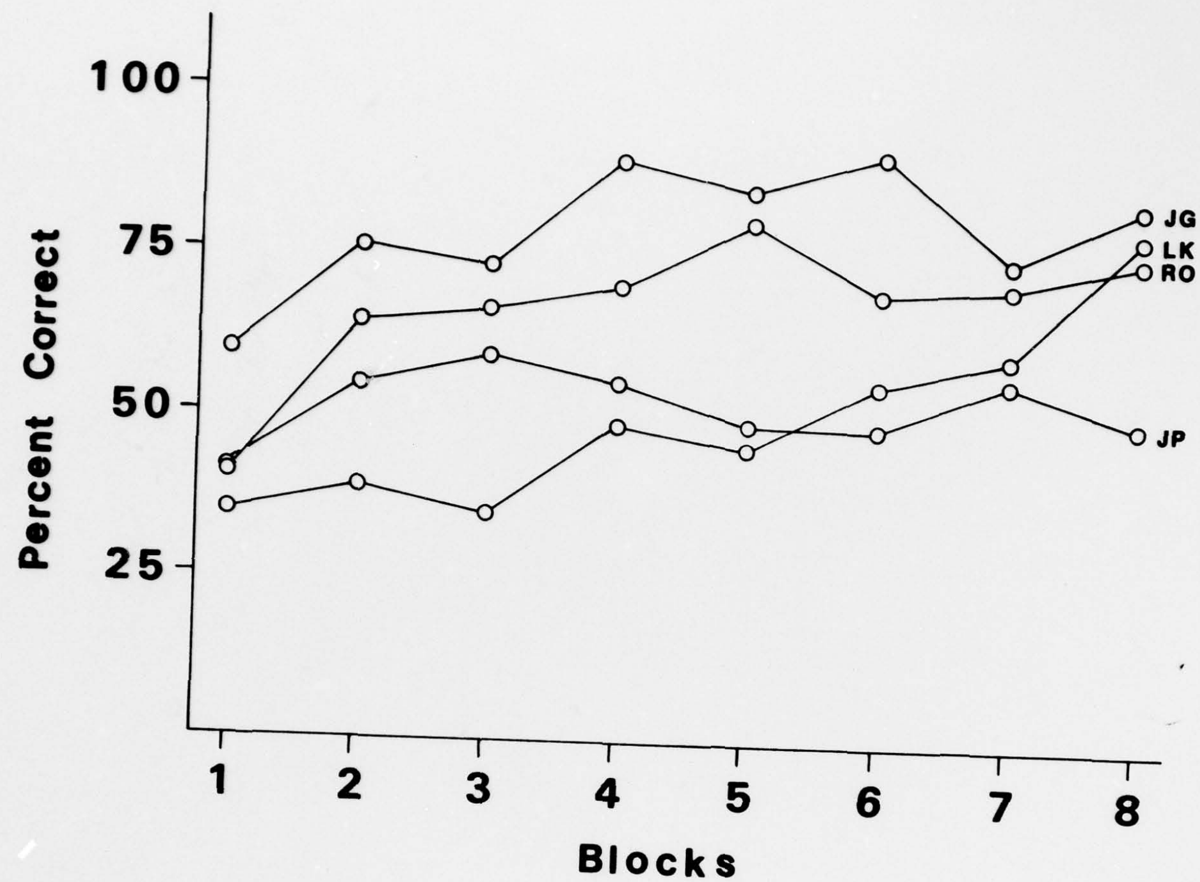

Figure 1. Overall performance by block for all four listeners on the Tempo partition.

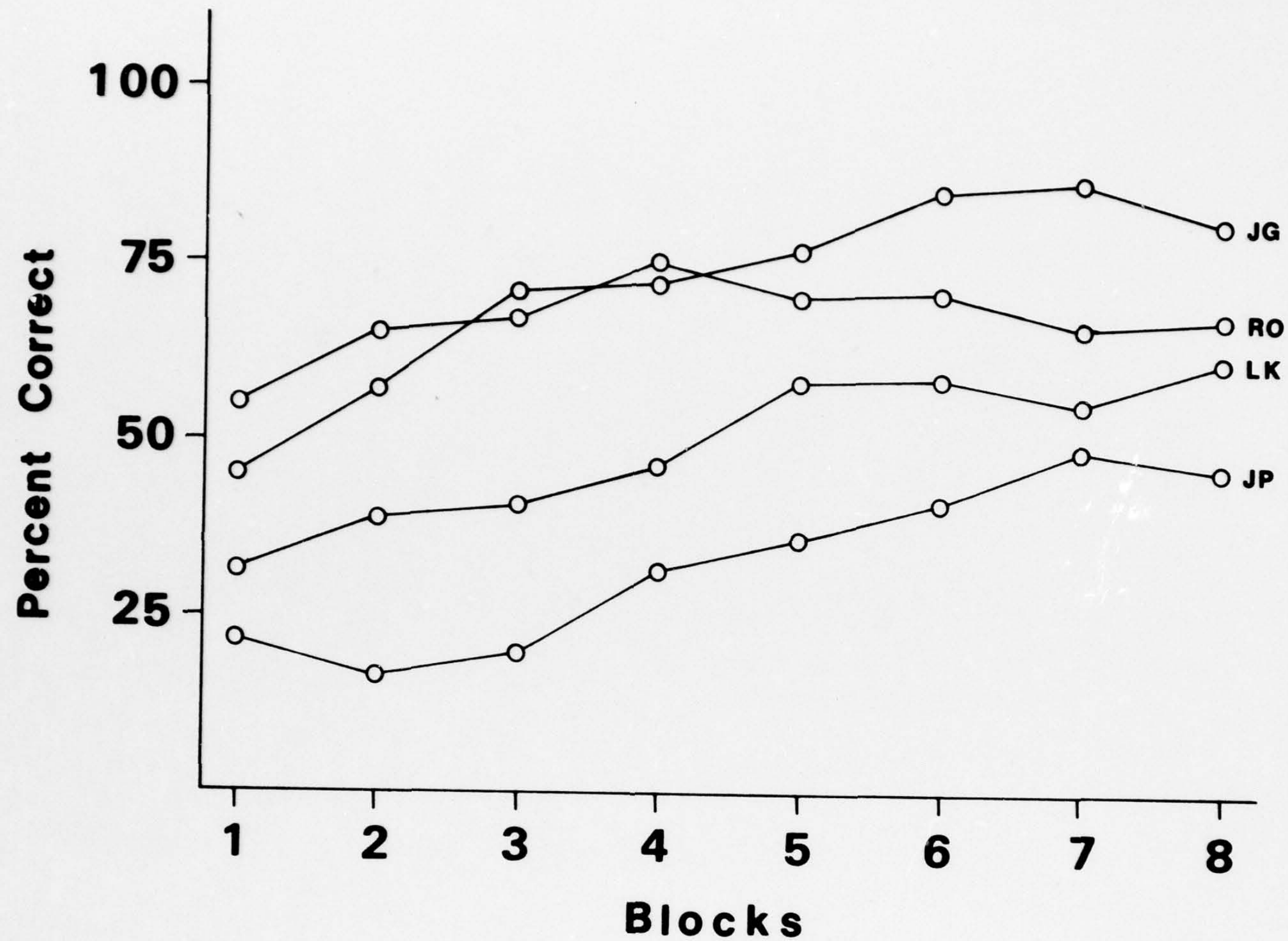

Figure 2. Overall performance by block for all four listeners on the Quality partition.

least squares sense. A standard, quasi-Newton gradient algorithm was used to perform the fits (subroutine ZXMIN in the IMSL mathematical library). The reciprocals of the standard deviation parameters were used to estimate a subjective weight for each feature, and the two weights were summed to estimate the total attentional effort. The predicted confusion matrices were then correlated with the observed matrices to determine the goodness of fit. Across all listeners and blocks, the model accounted for approximately 83% of the variance in the confusion matrices. The model accounted for 86% and 77% of the variance along the Tempo and Quality dimensions, a statistically significant difference ($\underline{z}$ = 12.73, $\underline{n}$ = 4096). There were also differences between listeners, with the model accounting for 94%, 85%, 74% and 64% of the variance for listeners JG, RO, LK and JP. Generally, these differences are directly related to the percent correct since accurate performance is more consistent and thus more predictable and more accurately modeled.

In order to assess the stability of individual differences, the variance parameters for the best four blocks in each partition were averaged and compared across listeners and partitions. An average of the best four blocks was used in order to get a more stable estimate of maximum performance. These averages are shown in Table 1, by listener and by partition.

Insert Table 1 here

The differences between listeners are greater than the

Table 1

Overall Attentional Effort by Partition and Listener

Partition	Listener JG	RO	LK	JP	Mean
Tempo	19.33	16.12	12.84	12.38	15.17
Quality	18.01	15.82	13.53	10.19	14.39
Mean	18.67	15.97	13.19	11.29	

differences between partitions. Specifically, the rank order of the listeners is the same for each partition. These results indicate that the level of overall effort changed more as a function of the listener than as a function of the dimension.

The overall effort parameter estimates the upper limit of capacity that applies to each listener, but within this limit, performance is dependent upon how the effort is allocated. That is, the available capacity may be allocated to either dimension in a manner that may or may not be optimal (i.e., maximize the average probability correct). Once the overall effort is estimated by the model, the optimal allocation of this capacity is easily found. In this study, all listeners were performing near optimal levels. Both the observed and optimal levels are shown in Figures 3-6.

Insert Figures 3 - 6 here

In almost every block, the observed performance is just slightly below the optimal level.

Since the observed performance was nearly optimal, the allocation of effort was necessarily close to optimal. This is shown in Table 2.

Insert Table 2 here

The optimal allocation for both partitions was about a 64% to 36%

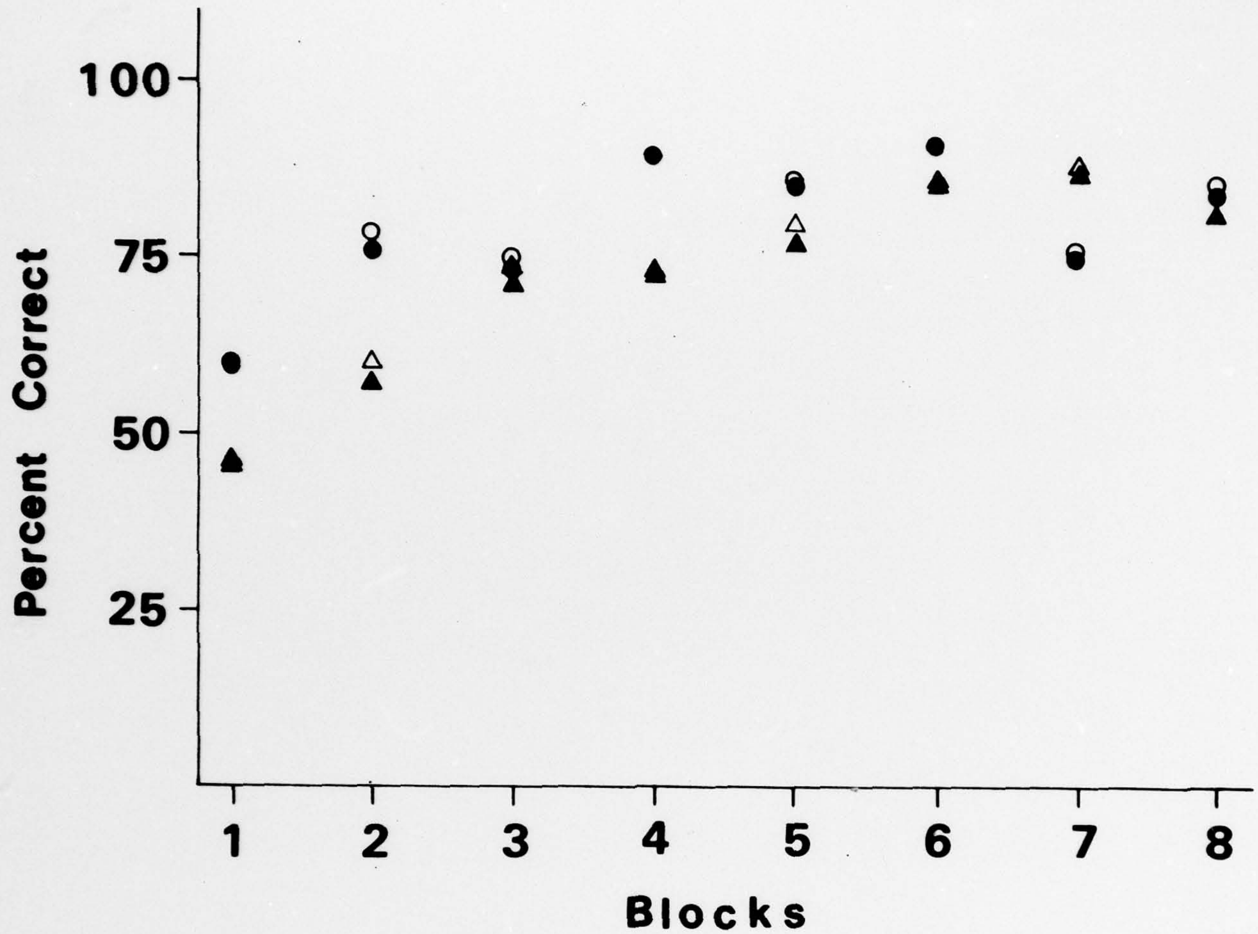

Figure 3. Observed (solid points) and optimal (open points) performance levels for listener JG on the Tempo (circles) and Quality (triangles) partitions by block.

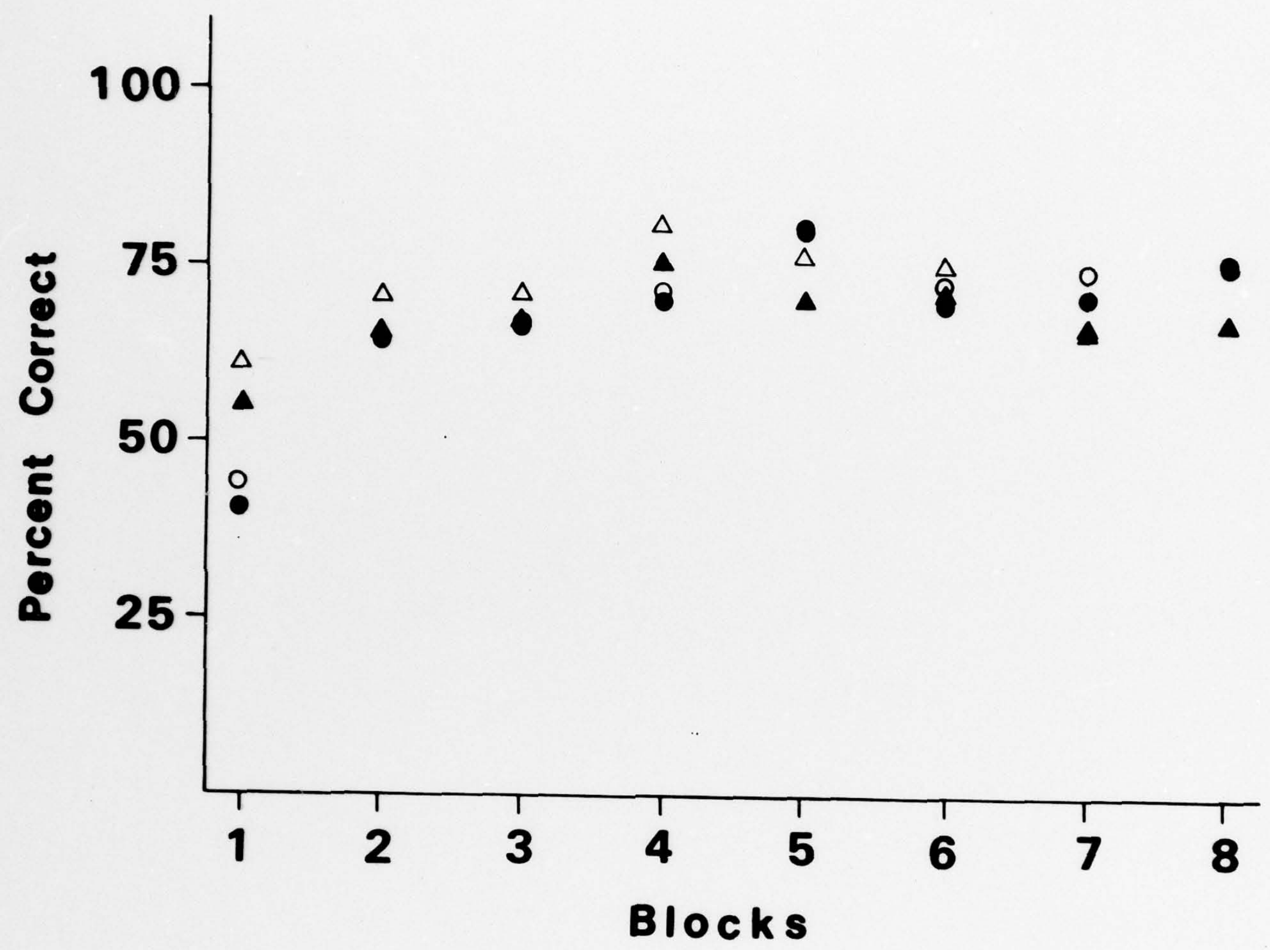

Figure 4. Observed (solid points) and optimal (open points) performance levels for listener RO on the Tempo (circles) and Quality (triangles) partitions by block.

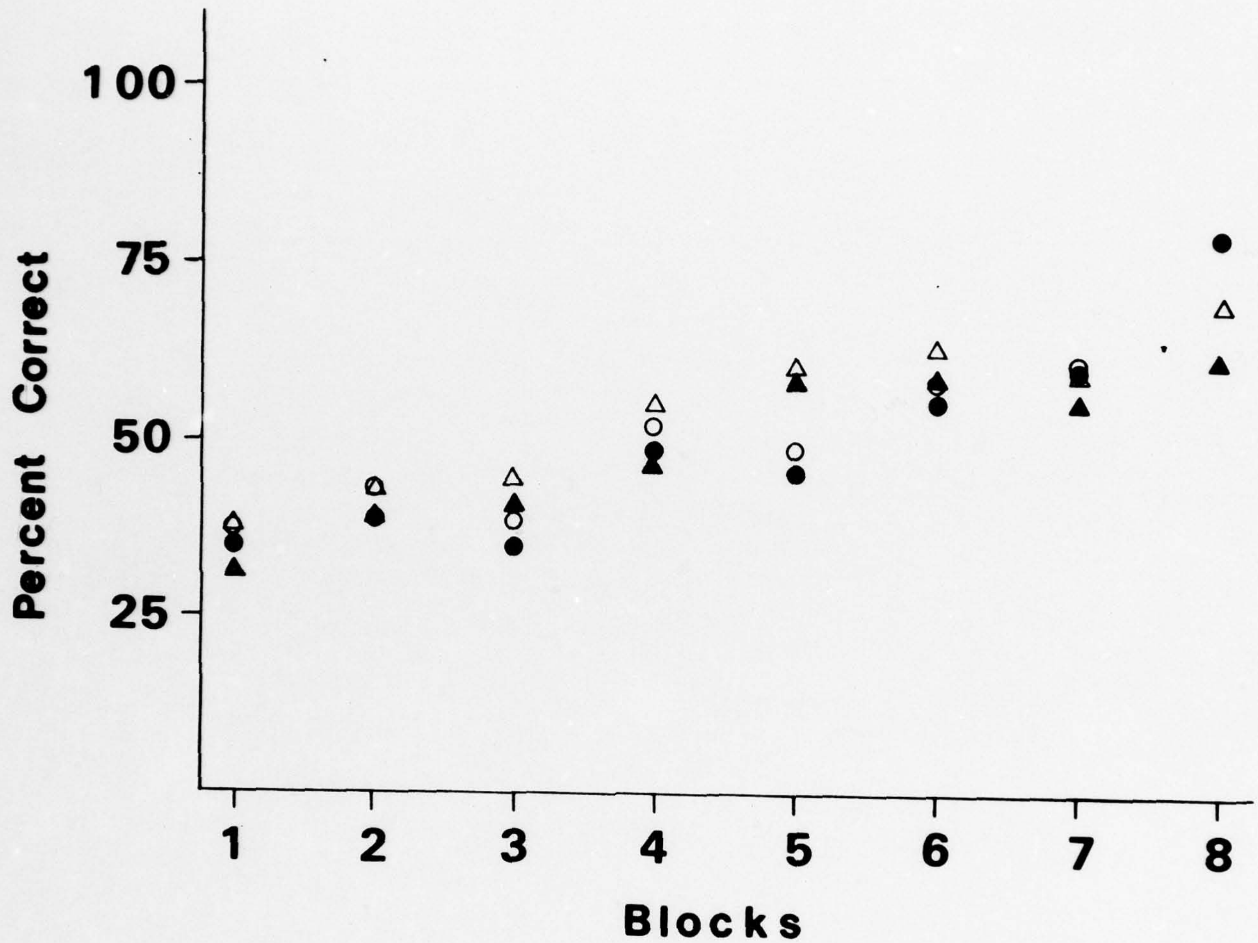

Figure 5. Observed (solid points) and optimal (open points) performance levels for listener LK on the Tempo (circles) and Quality (triangles) partitions by block.

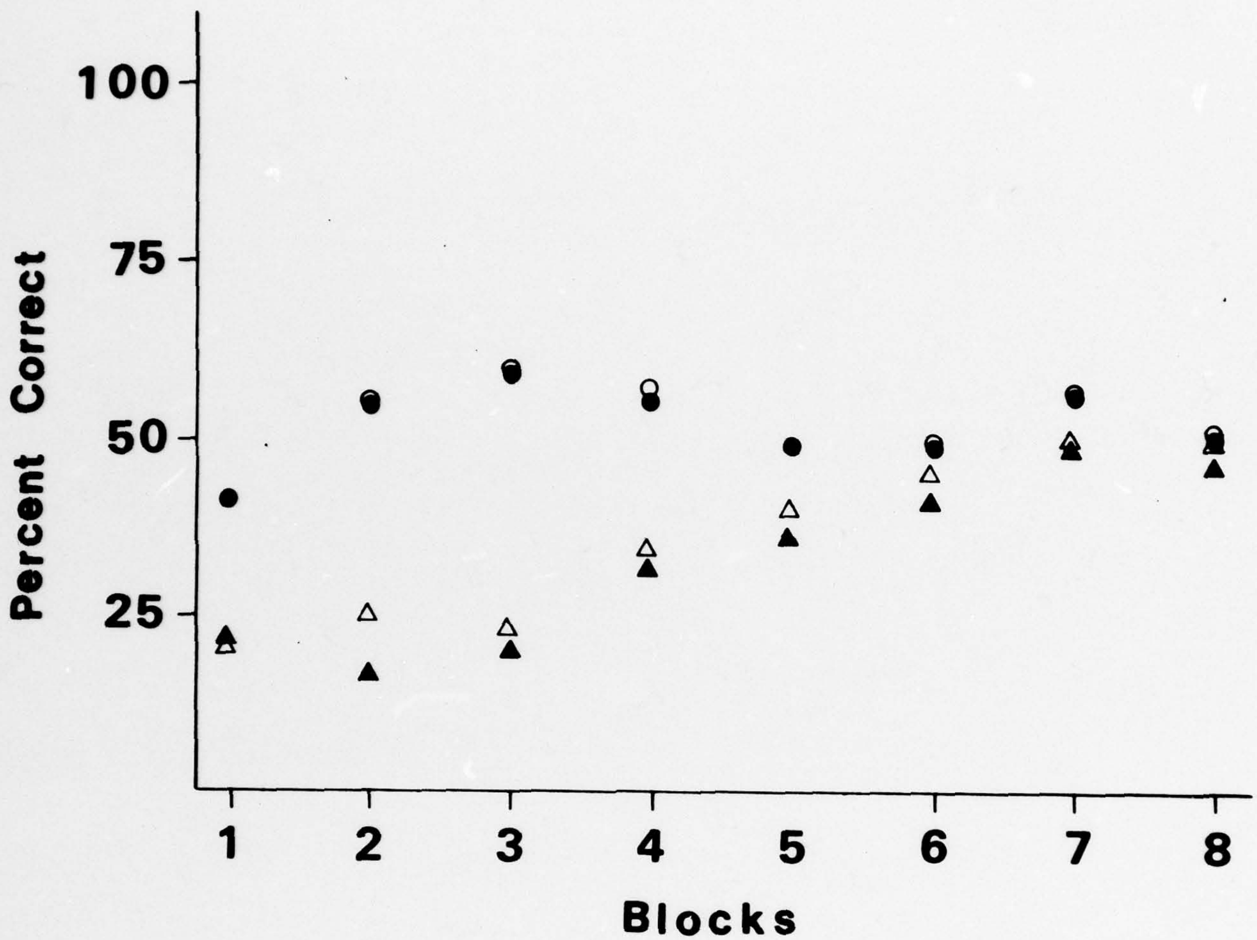

Figure 6. Observed (solid points) and optimal (open points) performance levels for listener JP on the Tempo (circles) and Quality (triangles) partitions by block.

Table 2

Observed and Optimal Tempo Emphasis by Partition and Listener

	Listener			
Partition	JG	RO	LK	JP
Tempo				
Observed	.60	.70	.77	.63
Optimal	.63	.65	.64	.64
Quality				
Observed	.40	.46	.49	.56
Optimal	.36	.35	.36	.38

ratio between the more and less relevant dimension. The observed allocation was biased toward Tempo in both partitions averaging 68% in the Tempo partition and 48% in the Quality partition. It seems likely that this overemphasis of the Tempo dimension resulted from the poor discriminability of the Quality dimension. Since the present stimuli were constructed to make both the Quality and Tempo discriminations more difficult than in previously investigated stimuli, it is possible that stimulus differences along the Quality dimension were approaching a sensory threshold.

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